

Introduction

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THE SUN AT CENTER STAGE

Global climate change due to greenhouse gas emissions from fossil fuel usage and the increased need for pure water are two pressing issues. With the ability of semiconductor nanoparticles to create electron-hole pairs upon irradiation with light, the sun, together with materials research, takes center stage for addressing these two urgent problems of our society: the increasing need for clean drinking water and water for sanitary purposes, and the need for CO₂-neutral energy and fuels.

Photocatalysis, the aforementioned process of electron-hole pair creation, with subsequent radical formation at the semiconductor surface, is an established method for the decomposition of organic contaminants and waste in water and on surfaces. The term photocatalysis shows up in literature as early as 1911 in an article in “*Zeitschrift für Elektrochemie und Angewandte Physikalische Chemie*,” which translates into “*Journal of Electrochemistry and Applied Physical Chemistry*.” Since then, the number of papers published on photocatalysis has grown steadily with 7,600 published items and over 134,000 citations to date. The 1911 article also provides an early link between photocatalysis and electrochemistry.

Titanium oxide, TiO₂ is the archetype photocatalyst. It is available as a commercial product under various brand names and is basically a commodity. TiO₂ and other

photocatalyst materials are able to perform water splitting by electrochemical photolysis under ultraviolet light illumination when assembled in photoelectrochemical cells (PEC).¹ The pioneering *Letter to Nature* by A. Fujishima and K. Honda in 1972² gives the first account of a useful method for photoelectrochemical water splitting, while these authors acknowledge earlier work done in 1910 by A. Coehn.³ The solar photoelectrochemical water splitting for hydrogen or hydrocarbon fuel generation is a promising, CO₂-neutral way to convert solar energy into chemical energy and thus storable and transportable fuel. While this approach is promising and has very high potential, there currently exists no technology and thus no market. In contrast, substantial revenues are already generated from technologies on photocatalysis for hygiene and sanitary purposes and environmental cleanup and remediation. A review on photocatalysis for environmental applications is one of the most highly cited (>4100) papers in the general field of photocatalysis.⁴

Recent and current research activities concentrate on doping the anion or cation site of TiO₂,^{5,6} or the design of alternative materials with suitable energy levels and band gaps, to make photocatalysts active under visible light. Materials of particular interest include iron-doped and nitrogen-doped TiO₂, tungsten oxide WO₃ and hematite Fe₂O₃ as well as materials with more complex crystallography and stoichiometries. In addition, development of heterostructures and complex architectures of semiconductors are of high interest.^{7,8}

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From the beginning of its existence, the Materials Research Society has been supportive of the dissemination of solar energy research. This Focus Issue of *Journal of Materials Research* was published to stimulate the cross fertilization of the two closely related topics of photoelectrochemistry and photocatalysis, and to respond to and account for the pressing needs for renewable and sustainable fuels and pure water by exploiting solar energy. With a total of 25 contributions, it provides a representative snapshot of current research activities in photocatalysis materials research for environmental clean-up and remediation, solar hydrogen fuel generation by PECs, and solar cells and related materials, systems, and components. The contributions cover active materials and coatings, nanocomposites, nanostructures and architectures, computational modeling, combinatorial chemistry, and one review for accelerated development with suggested metrological standards and testing protocols.

It is interesting that half of the contributions deal with either pure, doped, or otherwise modified TiO₂, although TiO₂ has been under investigation for many years. A rapidly emerging field is that of coupling plasmon resonances with the electron-hole pair, where photocatalyst materials are decorated with metal nanoparticles to sensitize the system to visible light. Ag/TiO₂ and Au/TiO₂ are currently standard systems. Another approach is to combine different semiconductor nanoparticles to form p-n heterojunctions. Naturally, these approaches take advantage of nanostructuring and demonstrate that more improvements can be attained by further nanoparticle surface or interface functionalization.

Other contributions in this issue deal with the dependency of photocatalytic and photoelectrochemical properties on the synthesis parameters, as is shown here for tungsten, cadmium, and of course, titanium-based materials. The ultimate goal is to have functional photocatalysts with sufficient activity for disinfection of microorganisms, as demonstrated here on metal and nitrogen doped titanium

oxide, or photoelectrochemical cells with sufficient efficiency. A couple of papers outline strategies about how to improve device architecture of hematite-based and dye-sensitized solar cells. In the expanding field of PEC hydrogen production, the use of standardized screening methods and reporting has emerged as an important necessity. *Accelerating materials development for photoelectrochemical (PEC) hydrogen production: Standards for methods, definitions, and reporting protocols* (Chen et al.) outlines a series of methods, definitions, and reporting protocols to standardize and accelerate the development of PEC materials.

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